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BRIGHTNESS OF MARS

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ABSTRACT. Results of the statistical processing
of the phase dependence of Mars brightness in the
spectral region between 0.3 and 1.1 µ are given. The
brightness variations with the longitude of the central
meridian are analyzed. It was found that reflectivity
of Mars falls down quickly between 0.4 and 0.6 µ, and
the law of reflection from the Martian surface changes
in this spectral region.

At the present time a great deal of both integral and surface observa-
tional material from photometry of Mars has been compiled. To provide a
more valid physical interpretation, and also to solve the problems involved,
it is necessary to generalize all of the existing material: to obtain, on
the one hand, the most probable average values of the photometric characteris-
tics of the planet, the spectral behavior of these characteristics with
phase, etc., and, on the other hand, to estimate the possible scatter of these
values, caused both by observational errors, and the natural scatter caused
by spatial nonuniformity of the surface and the atmosphere of the planet, as
well as the changes taking place in that time.

One of the studies in this direction is [1], which generalizes the data
on the geometric albedo of Mars. In this study the phase dependence of the
integral brightness of Mars is analyzed. Statistical processing is performed
of the basic observations of the monochromatic stellar magnitudes of Mars,

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which encompass the interval in which the phase angle changes which is assumed for observations from the Earth [2 - 6]. This study is of value, particularly in connection with the problem of the opposition effect of Mars [4, 7]. A problem similar to that which we have postulated was solved in [8]. However, it was for data averaged over individual, large spectral intervals.

The observed values of the stellar magnitude of Mars undergo significant fluctuations (up to $0^m.3$). The real component of these fluctuations is caused both by the longitudinal effects and by clouds and other meteorological phenomena [9]. The real brightness fluctuations were excluded, due to the fact that they have a definite spectral pattern, independently of the reasons for them.
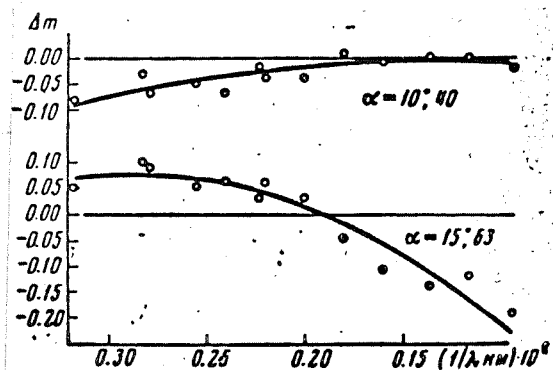

Figure 1. Typical curves for the systematic section $\Delta m(\lambda)$ over the spectrum.

In the first approximation, all of the curves $m(\alpha)$ were approximated by square parabolas. The differences $\Delta m = m_{obs.} - m_{app.}$ were represented as functions of the wavelength λ for a given value of the phase angle α. Then the systematic portion of the spectral behavior of $\Delta m(\lambda)$ (see Figure 1) was excluded from m_{obs}. Figure 2 gives the dependence of $m(\alpha)$ for λ 7297 Å, obtained in [2, 3] (Figure 2, a), and also the dependence after using the procedure described above (Figure 2, b) as an example.

The smooth dependencies $m(\alpha)$ were then expanded in series of orthogonal Chebyshev polynomials [10]
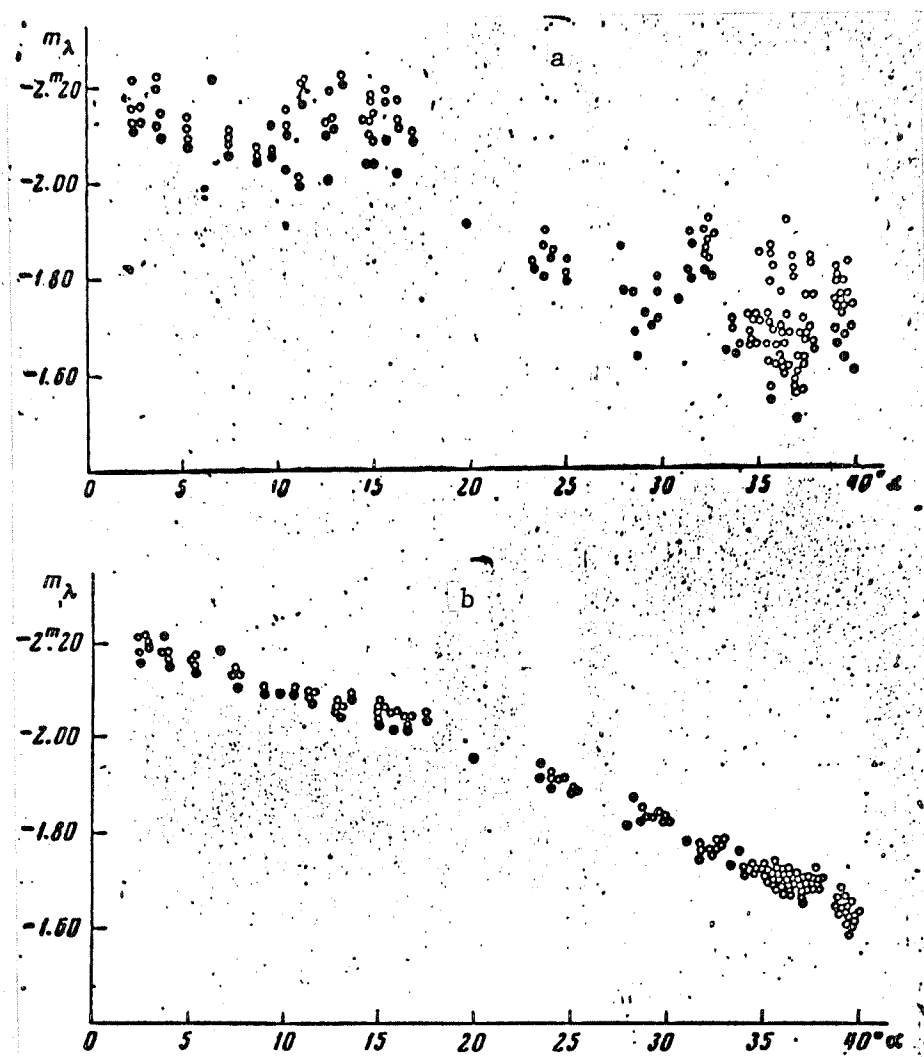
$$m(\alpha) = \sum_{k=0} c_k \varphi_k(\alpha). \tag{1}$$

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Figure 2. Phase dependence of m(α) for λ 7297 Å;
a - according to data in [2, 3]; b - smoothed
dependence.

The expansion coefficients were calculated until the following condition was
satisfied

$$(3)$$

where $\sigma^2(c_k)$ is the estimate of the dispersion of the coefficients c_k. This

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condition corresponds to the fact that the coefficient whose modulus was greater than 95% of the confidence interval for this coefficient was assumed to be significant.

Then the transition from expansion in Chebyshev polynomials to ordinary polynomials in powers of α is carried out. The results of the calculations are given in Table 1 (σ^2 are the mean square deviations of points on the curve from the calculated polynomial; γ_i — coefficients of this polynomial; $\sigma_{\gamma i}$ — mean square deviations of these coefficients).

Table 2 gives the results of similar treatment of the integral brightness of Mars in the UBV system based on data from [2, 3].

It can be seen from Table 1 that in the majority of cases, in the observed interval of phase angle values and for a given level of errors, the phase dependence of the integral brightness of Mars is described by a square parabola. The nonlinearity increases when a change is made from large wavelengths to shorter wavelengths, so that in the wavelength region of the spectrum the square term is sometimes insignificant, and the cubic term can be estimated in the short wave region at times.

The results of processing individual observations were reduced to one photometric system, to the system used in [2, 3], and then averaged with weights taking into account the number of observations, the average value, and the interval of the phase angle in which the observations were performed. The data in [4] were connected in an absolute manner by normalizing the integral with respect to α between 0 to 45°. The data in [6] were excluded in the averaging, as having rather large errors and an irregular spectral behavior.

The final results are given in Table 3. In the spectral interval where only observations from [2, 3] are given, the values of the mean square deviation of $\sigma_{\gamma i}$ were obtained by extrapolation and are given in the parentheses.

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TABLE 1

λ, Å	γ_0	σ_{γ_0}	$\gamma_1 \cdot 10$	$\sigma_{\gamma_1} \cdot 10$	$\gamma_2 \cdot 10^3$	$\sigma_{\gamma_2} \cdot 10$	$\gamma_3 \cdot 10^4$	$\sigma_{\gamma_3} \cdot 10^4$	$\sigma^2 \cdot 10^2$
Observations of W. M. Irvine et al. [2, 3]									
3147	$-0.^m620$	$0.^m022$	0.37₂	0.042	-0.761	0.222	**0.824**	**0.338**	0.112
3590	-0.562	0.009	0.256	0.010	-0.163	0.022	—	—	0.067
3926	-0.660	0.011	0.240	0.016	-0.095	0.031	—	—	0.161
4155	-0.763	0.018	0.185	0.035	0.360	0.183	**-0.806**	**0.277**	0.122
4573	-1.104	0.005	0.279	0.006	-0.196	0.013	—	—	0.027
5012	-1.315	0.007	0.276	0.008	-0.208	0.016	—	—	0.042
6264	-2.062	0.010	0.130	0.011	0.101	0.025	—	—	0.107
7297	-2.210	0.006	0.095	0.006	0.128	0.014	—	—	0.035
8595	-2.229	0.005	0.122	0.006	0.055	0.013	—	—	0.029
10635	-2.198	0.011	0.112	0.012	0.070	0.026	—	—	0.122
Observations at the Main Astronomical Observatory of the USSR Acad of Sciences [4]									
3550	3.164	0.017	0.517	0.046	-1.029	0.279	**1.002**	**0.499**	0.042
3900	3.138	0.012	0.459	0.015	-0.497	0.040	—	—	0.041
4300	2.809	0.017	0.421	0.022	-0.457	0.058	—	—	0.087
4800	2.647	0.021	0.470	0.027	-0.557	0.070	—	—	0.128
5300	2.304	0.015	0.337	0.019	-0.337	0.050	—	—	0.065
5430	2.257	0.011	0.366	0.014	-0.382	0.037	—	—	0.036
5900	1.934	0.007	0.251	0.009	-0.154	0.023	—	—	0.013
6190	1.919	0.010	0.215	0.012	-0.093	0.033	—	—	0.028
Observations of Wolley et al. [5]									
4050	0.487	0.019	0.043	0.017	0.299	0.033	—	—	0.108
4250	0.237	0.018	0.061	0.016	0.236	0.031	—	—	0.093
4550	-0.463	0.007	0.163	0.002	—	—	—	—	0.037
4945	-0.903	0.013	0.186	0.011	-0.082	0.022	—	—	0.048
5430	-1.337	0.016	0.132	0.005	—	—	—	—	0.178
5980	-2.036	0.013	0.170	0.016	-0.092	0.030	—	—	0.091
6360	-2.150	0.021	0.032	0.019	0.171	0.037	—	—	0.134
Observations of N. B. Ibragimov [6]									
4050	0.267	0.030	0.227	0.010	—	—	—	—	0.397
4150	0.068	0.045	0.299	0.036	-0.149	0.067	—	—	0.151
4250	-0.190	0.027	0.411	0.022	-0.353	0.040	—	—	0.055
4350	-0.375	0.040	0.433	0.032	-0.413	0.059	—	—	0.117
4450	-0.569	0.049	0.438	0.039	-0.414	0.072	—	—	0.174
4550	-0.741	0.052	0.442	0.042	-0.434	0.077	—	—	0.199
4700	-0.845	0.041	0.353	0.033	-0.274	0.060	—	—	0.123
4800	-0.856	0.047	0.280	0.037	-0.155	0.069	—	—	0.153
4945	-0.854	0.019	0.166	0.006	—	—	—	—	0.156
5050	-0.936	0.016	0.162	0.005	—	—	—	—	0.109
5100	-0.920	0.029	0.068	0.023	0.181	0.042	—	—	0.061
5150	-0.925	0.031	0.058	0.025	0.220	0.046	—	—	0.072
5200	-0.901	0.036	-0.027	0.029	0.329	0.053	—	—	0.095
5250	-0.900	0.031	-0.072	0.025	0.401	0.046	—	—	0.072
5300	-1.110	0.051	0.026	0.041	0.232	0.075	—	—	0.190
5430	-1.382	0.018	0.154	0.006	—	—	—	—	0.146
5550	-1.568	0.056	0.259	0.043	-0.230	0.078	—	—	0.191
5700	-1.702	0.016	0.146	0.005	—	—	—	—	0.103
5980	-1.877	0.022	0.105	0.008	—	—	—	—	0.192
6360	-2.110	0.025	0.100	0.008	—	—	—	—	0.240

TABLE 2

	γ_0	σ_{γ_0}	$\gamma_1 \cdot 10$	$\sigma_{\gamma_1} \cdot 10$	$\gamma_2 \cdot 10^3$	$\sigma_{\gamma_2} \cdot 10^3$	$\gamma_3 \cdot 10^5$	$\sigma_{\gamma_3} \cdot 10^5$	$\sigma^2 \cdot 10^3$
U	0.m222	0.m021	0.360	0.039	−0.834	0.205	1.128	0.310	0.177
B	−0.216	0.006	0.184	0.002	−	−	−	−	0.090
V	−1.509	0.004	0.169	0.002	−	−	−	−	0.055

TABLE 3

| λ, нм	γ_0	σ_{γ_0}	$\gamma_1 \cdot 10$	$\sigma_{\gamma_1} \cdot 10$	$\gamma_2 \cdot 10^3$	$c_{\gamma_2} \cdot 10^9$
315	−0.m58	(0.m09)	0.276	(0.083)	−0.226	(0.145)
350	−0.61	0.09	0.316	0.083	−0.267	0.145
400	−0.72	0.15	0.252	0.146	−0.124	0.291
450	−1.04	0.11	0.290	0.101	−0.210	0.181
500	−1.41	0.09	0.289	0.083	−0.212	0.232
550	−1.71	0.04	0.238	0.084	−0.140	0.106
600	−1.95	0.05	0.183	0.035	−0.032	0.082
650	−2.12	(0.05)	0.128	(0.035)	0.088	(0.082)
750	−2.22	(0.05)	0.094	(0.035)	0.126	(0.082)
850	−2.23	(0.05)	0.117	(0.035)	0.065	(0.082)
10500	−2.20	(0.05)	0.115	(0.035)	0.070	(0.082)
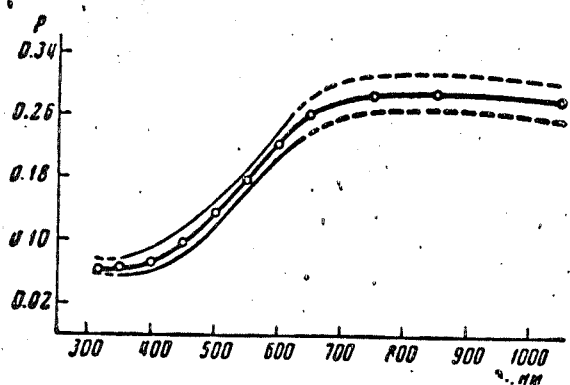
Figure 3. Pattern of the geometric albedo of Mars over the spectrum.

Figure 3 shows the behavior of the geometric albedo of Mars in the region 0.3 − 1.1 µ corresponding to the second column of Table 3.

For data in [2, 3], curves were drawn up of the longitudinal effect of the integral brightness of Mars (Figure 4) obtained by graphic averaging (the initial data are given as an example only for λ 10635 Å).

The maps of Mars given in [11, 12] were used to determine the relative area of seas on the hemisphere with the given longitude of the central
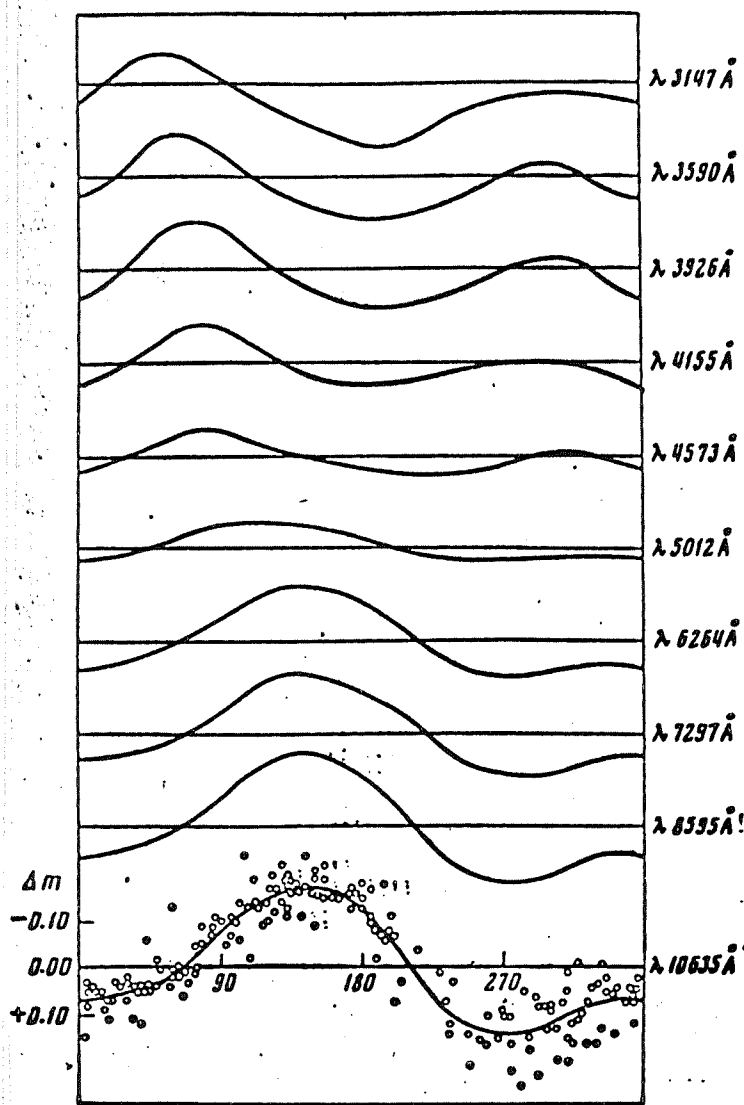
Figure 4. Longitudinal effects of the integral brightness of Mars in different spectral regions.

meridian. A comparison of the characteristics of the curves for the longitudinal effect of brightness and the number of seas is made in Figure 5. It can be seen that there is a correlation between the minimum brightness and the maximum number of seas in the long wave spectral region, which is natural. In the short wave region, the maximum number of seas is correlated with the maximum brightness. This means /586 that in the given spectral region the integral brightness of the planet, which is covered only by seas, exceeds the integral brightness of the martian continents completely. This may be related not only to a difference in albedo, but also to different laws governing the darkening toward the edge of the disk on the seas and continents of Mars. The conclusion was advanced recently [13] that there are different laws governing the reflection of light from seas and continents in the visible spectral region based on data from surface photometry.

An analysis of the spectral behavior of the geometric albedo and the phase coefficients also fostered the conclusion that in the region $0.4 - 0.6$ μ
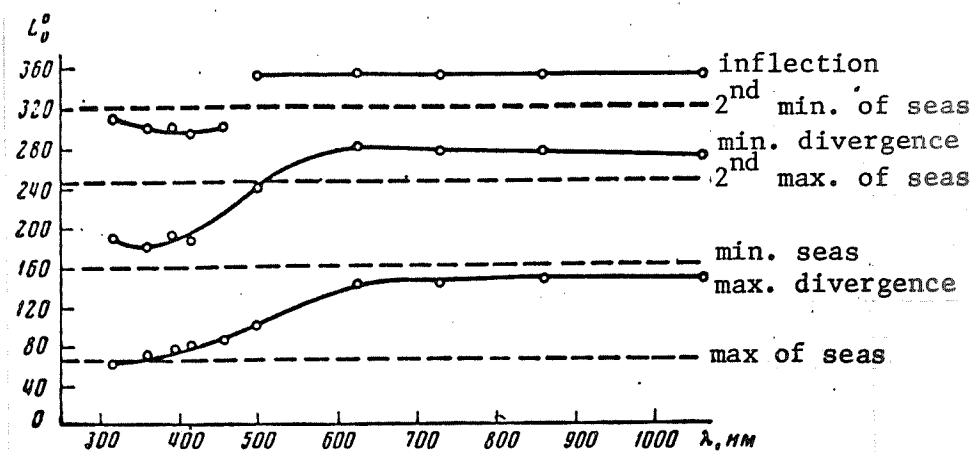
Figure 5.   Comparison of the characteristics
of the longitudinal affect $\Delta m(L)$ and the
number of seas.

there is a rapid change both in the reflectivity, and in the law governing
reflection of light from the surface.

The phenomenon of a change in the law governing reflection of light
over the spectrum is connected with a change in the role of scatter
ing of higher orders when the reflectivity changes. This phenomenon is
observed during indicator measurements of terrestrial samples. However, on
the Martian surface this change is very clearly expressed (see also [14]) and
is its characteristic photometric feature. This feature, which requires
that the spectral behavior of the optical constants of the substance be com-
bined with the properties of the surface micro-relief, must be taken into
account when interpreting the optical properties of the surface of Mars and
when identifying the components of its rocks. In particular, this is
connected with the semi-transparency of micro-relief elements on the Martian
surface.

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